

Solid Oxide Fuel Cell Seal Glass-BN Nanotubes Composites

Narottam P. Bansal, Sung R. Choi, Janet B. Hurst, and Anita Garg
NASA Glenn Research Center, Cleveland, Ohio 44135, U.S.A.

Solid oxide fuel cell seal glass G18 composites reinforced with ~4 weight percent of BN nanotubes were fabricated via hot pressing. Room temperature strength and fracture toughness of the composite were determined by four-point flexure and single edge V-notch beam methods, respectively. The strength and fracture toughness of the composite were higher by as much as 90 % and 35 %, respectively, than those of the glass G18. Microscopic examination of the composite fracture surfaces using SEM and TEM showed pullout of the BN nanotubes, similar in feature to fiber-reinforced ceramic matrix composites with weak interfaces. Other mechanical and physical properties of the composite will also be presented.

SOFC Seal Glass - Boron Nitride Nanotubes Composites

**Narottam P. Bansal*, Sung R. Choi, Janet B. Hurst,
and Anita Garg**

**NASA Glenn Research Center
Cleveland, Ohio 44135, U.S.A.**

**International Conferences on Modern Materials &
Technologies (CIMTEC 2006)**

Acireale, Sicily, Italy; June 4-9 (2006)

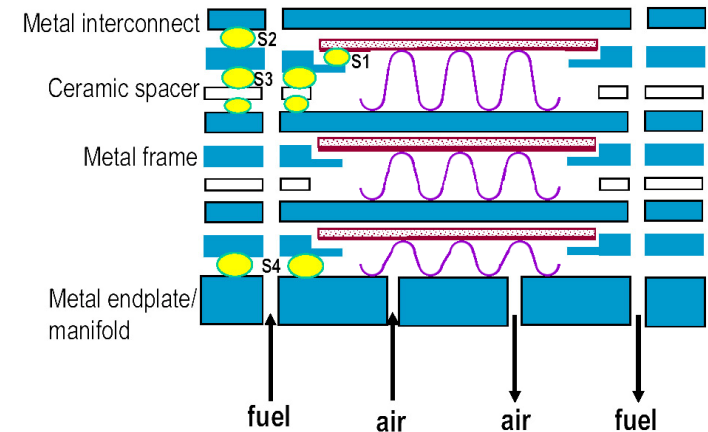
Planar Solid Oxide Fuel Cell (SOFC) Seals

Seal Requirements

- Hermetic to separate and contain fuel and oxidant within the cell and to bond cell components together
- Chemically and mechanically compatible with various SOFC oxide and metallic components and electrical insulator

SOFC Seal Glass

- Composition (mol %): 35BaO-15CaO-5Al₂O₃-10B₂O₃-35SiO₂ (BCAS)
- Low mechanical reliability due to low strength (50 MPa) and low fracture toughness ($K_{Ic} < 1 \text{ MPa}\cdot\sqrt{\text{m}}$) -- resulting in limited seal life



S1: PEN to Frame

Ceramic to Metal Seal

S2: Interconnect to Frame

Metal to Metal Seal

S3: Frame to Spacer

Metal to Ceramic Seal

S4: Frame to Endplate

Metal to Metal Seal

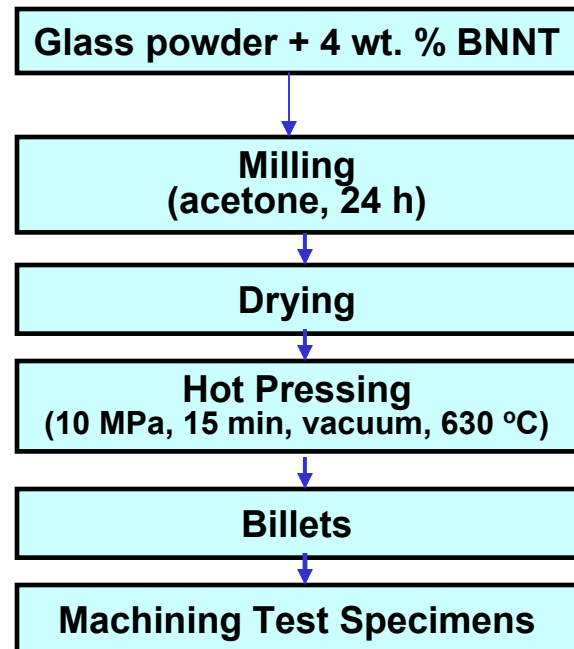
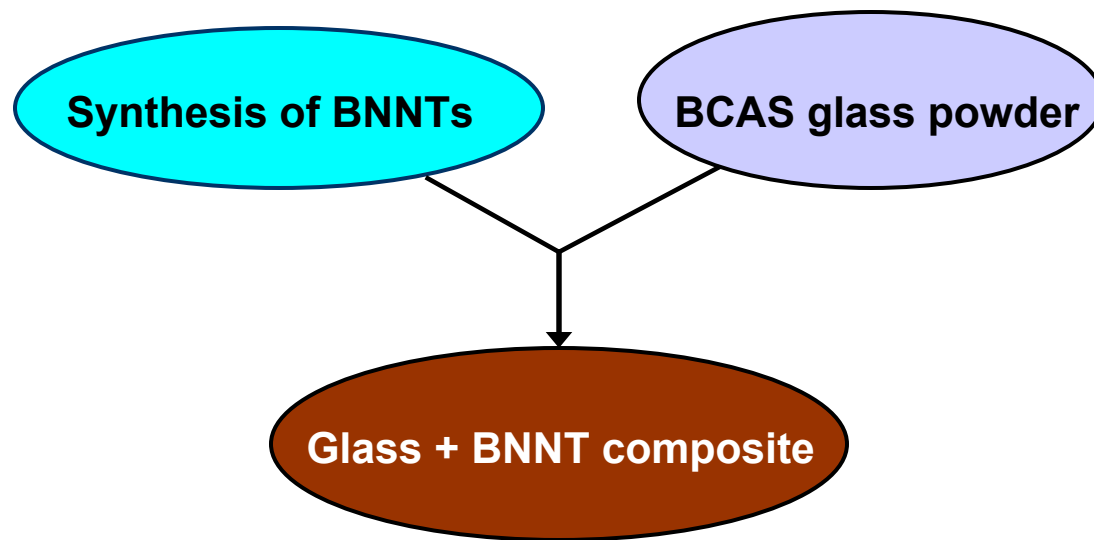
Objective

- **Improve strength and fracture toughness of SOFC seal glass (BCAS)**

Approach

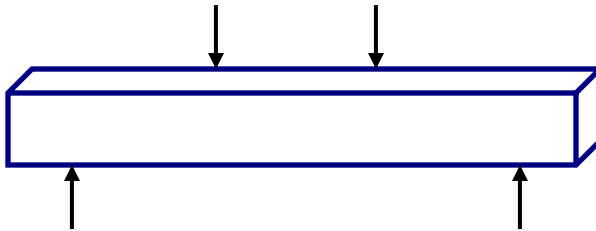
- **Reinforce BCAS glass with BN nanotubes (BNNTs)**
- **Characterize glass-BNNT composite by SEM/TEM**
- **Measure mechanical properties of composite**
- **Fractography of composite fracture surfaces**

Fabrication of BCAS glass-BNNT Composite



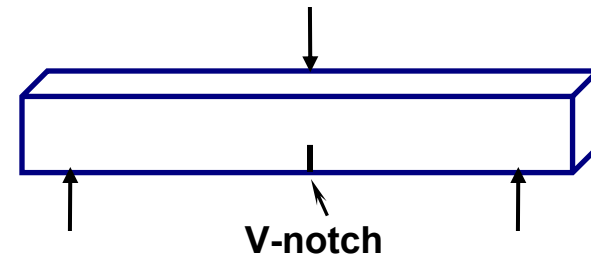
Mechanical Properties Evaluation

Strength



- Test bars: 2 mm x 3 mm x 25 mm
- Test rate: 50 MPa/s
- Test temperature/environment: RT/air
- No. of test specimens: 10
- Test method: ASTM C 1611 (4-point Bend)

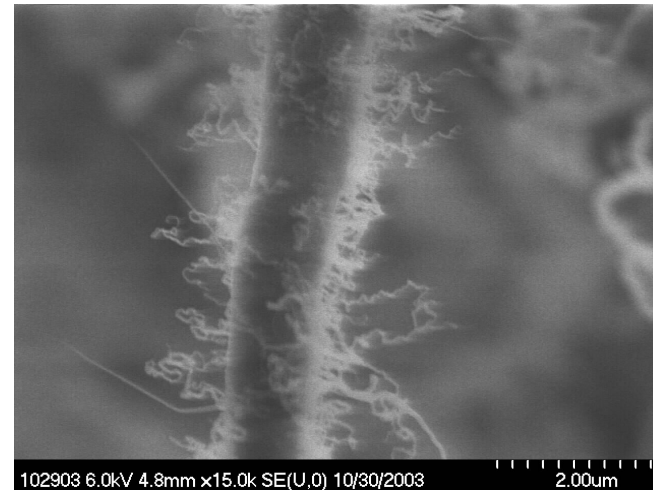
Fracture toughness



- Test bars: 2 mm x 3 mm x 25 mm
- Test rate: 0.5 mm/min
- Test temp/environment: RT/air
- No. of test specimens: 3
- Test method: single edge V-notched beam (SEVNB)

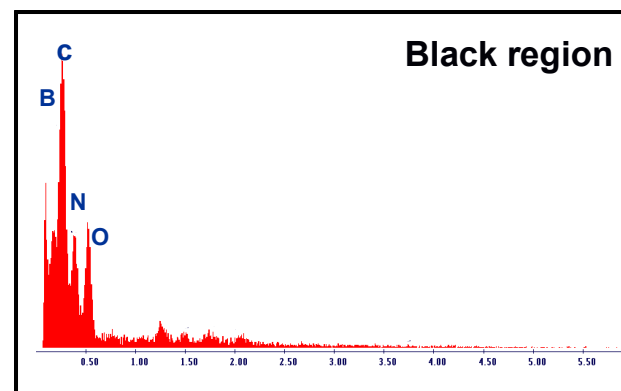
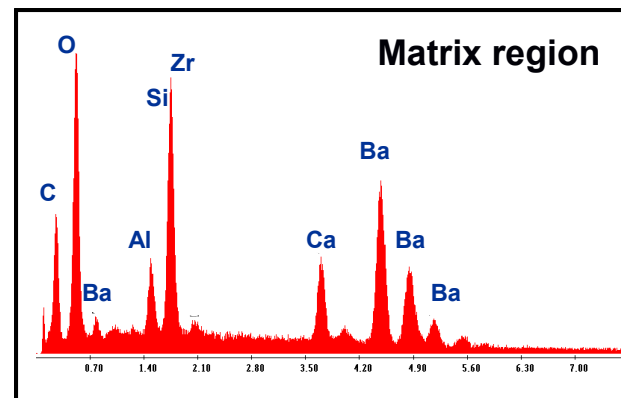
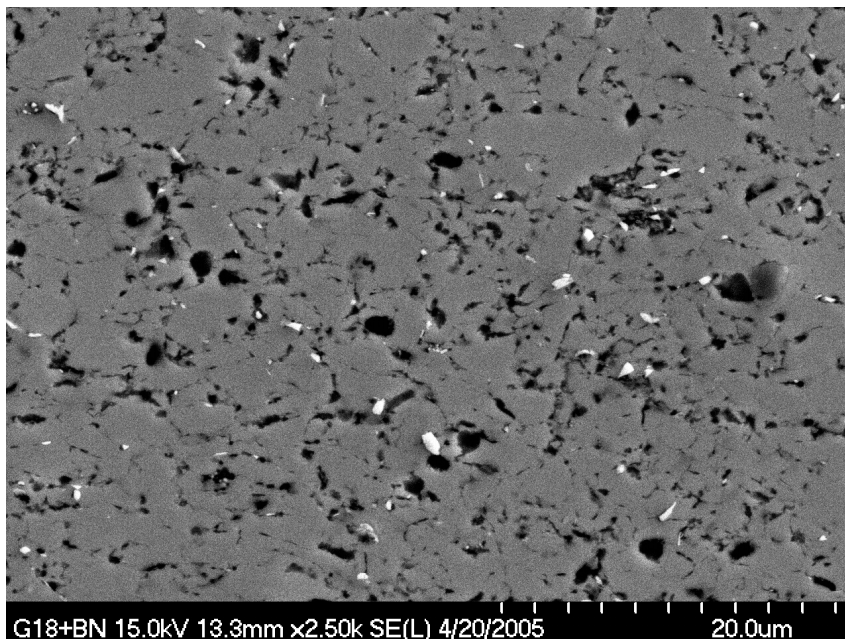
- Elastic modulus (impulse excitation, ASTM C1259)
- Vickers hardness (ASTM C1327)
- Density (mass/volume)

FESEM Microstructures of BNNTs



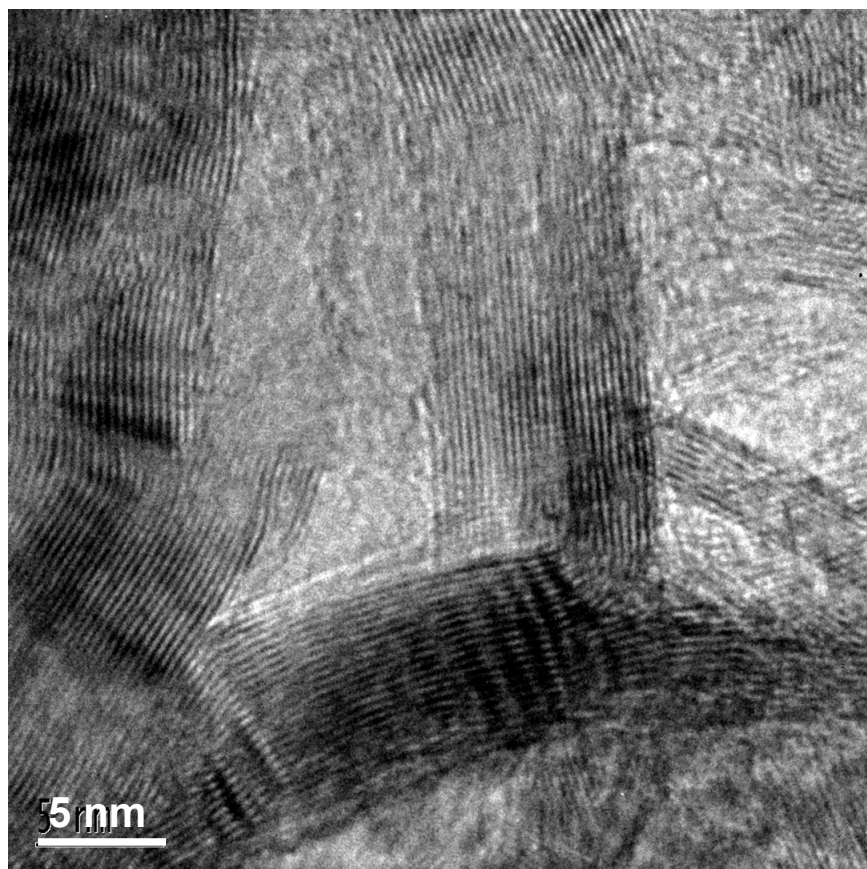
- Diameter: tens to hundreds of nanometers
- Length: tens of micrometers

SEM/EDS of Glass-BNNT Composite

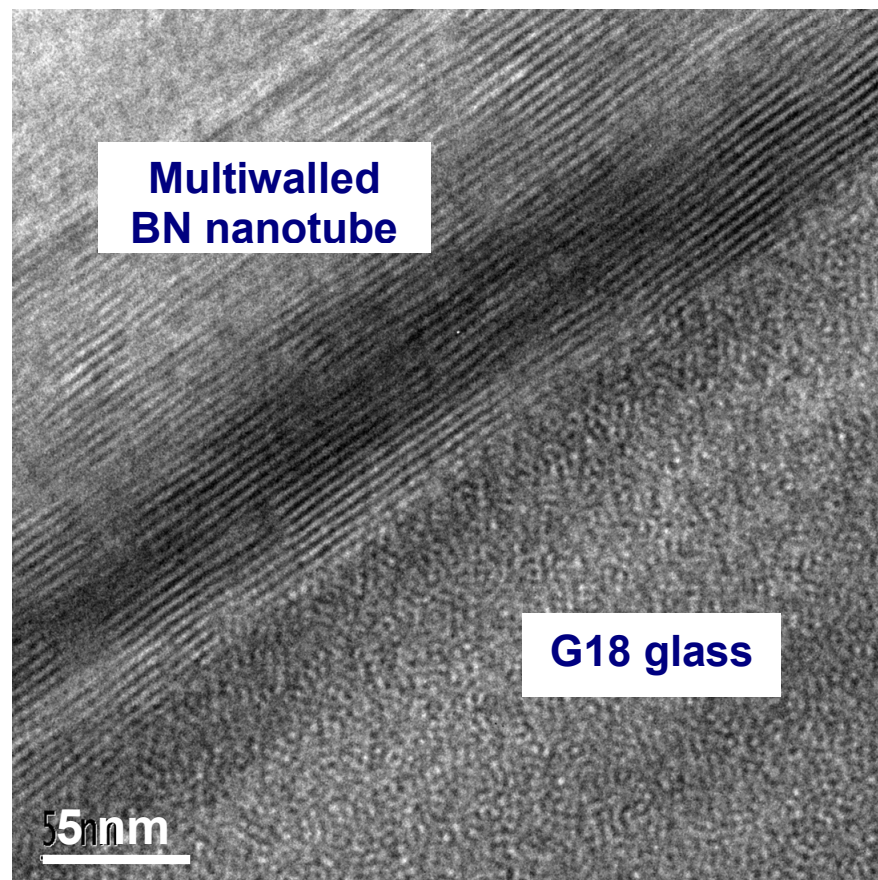


Black regions: BNNT clusters

TEM of Glass-BNNT Composite

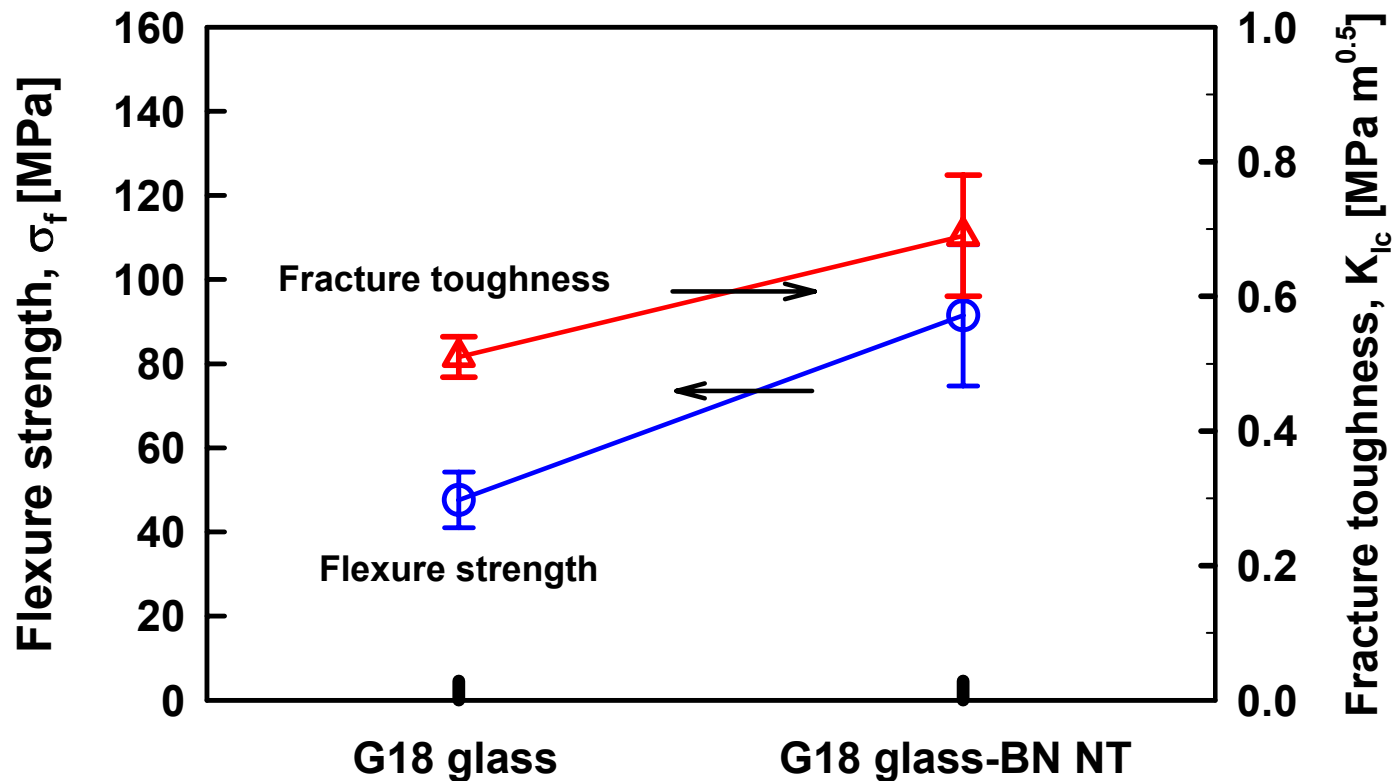


Lattice structure and clusters of multiwalled BNNTs in composite



BNNT/glass interface in the composite

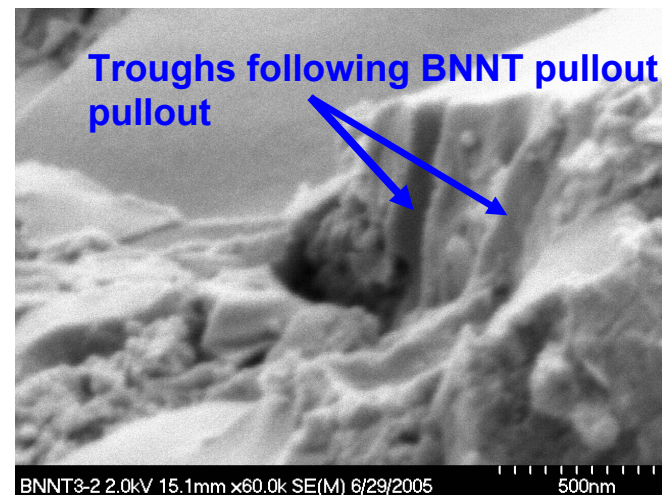
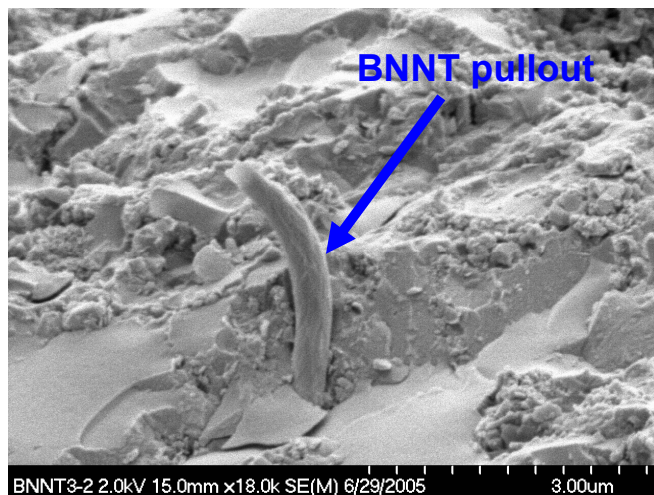
Strength and Fracture Toughness



- Significant strength increase (90%): from 48 ± 7 MPa for glass to 92 ± 17 MPa for composite
- Flaws: mostly volume (pores) associated
- Fracture toughness increased (35%): from 0.51 ± 0.037 $\text{MPa}\sqrt{\text{m}}$ for glass to 0.70 ± 0.09 $\text{MPa}\sqrt{\text{m}}$ for composite

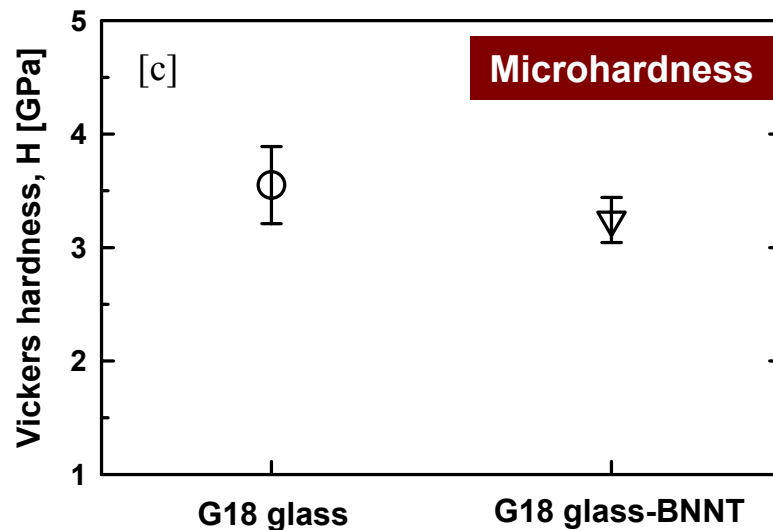
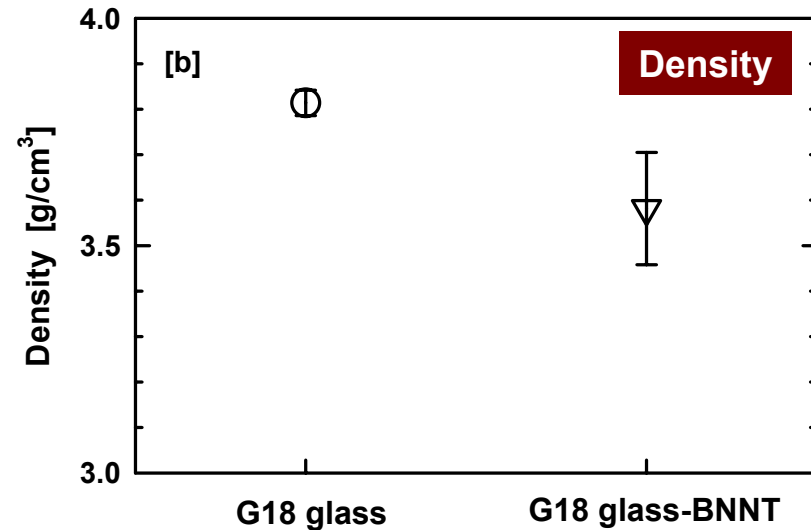
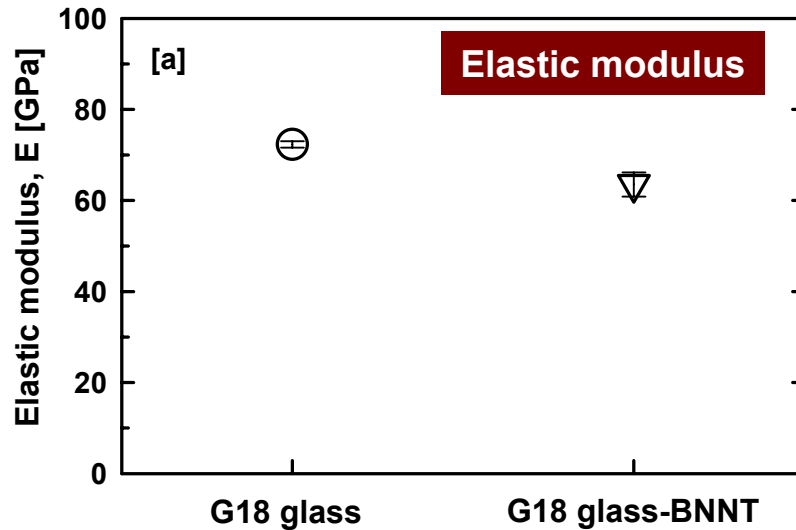
SEM of Fracture Surfaces

Glass-BNNT Composite



- Fracture surfaces showing pullout of BNNTs and resulting troughs
- Bridging may be a major contributing factor for reinforcement

Elastic Modulus, Density, & Hardness



Rule of mixture not-applicable to elastic modulus and density
(Density: glass = 3.814; BN = 2.2;
Composite = 3.582 g/cm³)

Summary and Conclusions

- **BCAS glass composites reinforced with 4 wt % BNNTs fabricated (1st time ever)**
- **Reinforcement of BCAS glass with 4 wt % BNNTs results in:**
 - **Significant increase (90 %) in flexure strength**
 - **Moderate increase (35 %) in fracture toughness**
 - **Lower elastic modulus, density and hardness**
- **Rule of mixture not-applicable to modulus and density**
- **BNNT pullout is the toughening mechanism**
- **Addition of 4 wt% BNNTs will have little effect on viscosity of BCAS glass and its sealing behavior at SOFC operating temperatures**

Acknowledgements

- **Ralph Pawlik for mechanical testing and John Setlock for composite processing**
- **This work was supported by Low Emission Alternative Power (LEAP) and Alternate Energy Foundation Technology (AEFT) Programs, NASA Glenn Research Center, Cleveland, OH**